Proton SEE Test Plan V1.0
STAR1000 1Mpixel Radiation Hard CMOS image sensor

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I. Introduction

This study is being undertaken to determine the proton induced single event destructive and transient susceptibility of the STAR1000 1Mpixel radiation hard CMOS image sensor from Fill Factory. The device was monitored for transient perturbations in the image by exposing it to a proton beam at the UC Davis, CA, Single Event Effects Test Facility.

II. Devices Tested

The sample size of the testing is 4 devices. 1 device was not exposed as control sample, and another device will serve as spare part. The device is manufactured by Fill Factory. The device package marking is FF, STR1K-BK7.

The device technology is CMOS. The device is packaged in a 84 lead ceramic chip carrier.

III. Test Facility

Facility: UC Davis, CA

Proton energy: 63 MeV

Angle of incidence: 0 degree and grazing incidence
Flux: 8×10^7 to 9×10^7 particles/cm^2/s.
Fluence: All tests were run to 1×10^{10} p/cm^2

IV. Test Conditions and Error Modes

Test Temperature: Room Temperature
Operating Frequency: 12 MHz
Power Supply Voltage: 5V.
Integration time: 8 to 255 increments of row readout time (6.8×10^{-4}s to 2.2×10^{-2} s)
Target image: dark and test frame
PARAMETERS OF INTEREST: Power supply currents, Image quality

SEE Conditions: Single Event Latchup (SEL), Single Event Functional Interrupt (SEFI), Single Event Upset (SEU), Single Event transients (SET)

V. Test Methods

Fill Factory STAR-1000 evaluation kit has been used for the test. The STAR-1000 evaluation kit consists of a multi functional digital board (memory, sequencer, and IEEE 1394 Fire Wire interface), an analog image sensor board, and a DUT board.
The digital board contains the controller for the image sensor under test. The main function of this board is to generate the digital signals that are required to operate the image sensor under its nominal operating conditions and timing.
The analog board contains the power supply regulators and buffers for voltage conversion of the signals between the digital controller and the module that contains the image sensors. The power regulators also allow measuring the supply currents to the DUT (image core, digital part, ADC). The signal buffers allow the DUT to be operated at nominal frequency over a cable with length up to 2 meters.
The DUT board can contain 1 image sensor and is used to operate the sensor at nominal conditions for the test.
Visual basic software (under Windows 2000 or XP) allows the grabbing of images from the sensor. All acquired images can be stored in different files format (8 or 16 bit). All setting can be adjusted on the fly to evaluate the sensors specifications. Default register values can be loaded to start the software in a desired state. The images are captured at nominal image sensor image frame rate of 2 frames/second.
A picture of the system is shown in Figure 1.

Figure 1: STAR-1000 evaluation kit:
DUT board, cable, and test system.

During irradiation the image sensor is operated under nominal conditions, the images are captured in the image controller module and transferred to the computer. The image

controller firmware incorporates power supply current measurement data as extra columns in the image that is transferred. Every different kind of power supply is monitored separately such that in the case of an over-current condition, the corresponding part of the image sensor can be identified. The firmware also allows setting trip points on the current measurement data. When one of the monitored current reaches a trip point, the DUT power supplies are shutdown, the time of the event is recorded, the last image is downloaded and saved, and the tripped power supply is identified.
The image sequence is captured at the nominal clock read-out under irradiation. The image sequence is stored locally in the image controller such that there is no idle time between images. This operation limits the number of images that can be taken to 200 images. After capturing the images in the local memory, they are transferred manually to the computer via the Fire Wire link where they are saved as separate images. Images can then be analyzed after irradiation. For each run one image was saved before the beginning of irradiation, and several were saved during the irradiation run.

VI. Test Results

Table 1 shows the irradiation test sequence. All three test samples have been irradiated with 63MeV protons up to a total fluence of 8 x 10^{10} p/cm^2.

Run #	SN #	Energy (MeV)	Angle	Exposure time (s)	inc dose (kRad-Si)	normal inc fluence (#/cm2)	normal total fluence (#/cm2)	tot dose (krad-Si)	int. time [increment of row readout time]	Target
100	1	63.3	0	114	1.3470	1.00E+10	1.00E+10	1.3470	8	dark
101	1	63.3	0	115	1.3470	1.00E+10	2.00E+10	2.6940	255	dark
102	1	63.3	0	116	1.3480	1.00E+10	3.00E+10	4.0420	128	dark
103	1	63.3	0	117	1.3540	1.00E+10	4.00E+10	5.3960	255	ref
104	1	63.3	grazing	117	1.3510	1.00E+10	5.00E+10	6.7470	8	dark
105	1	63.3	grazing	116	1.3490	1.00E+10	6.00E+10	8.0960	255	dark
106	1	63.3	grazing	118	1.3520	1.00E+10	7.00E+10	9.4480	128	dark
107	1	63.3	grazing	116	1.3530	1.00E+10	8.00E+10	10.8010	255	ref
108	2	63.3	0	115	1.3520	1.00E+10	1.00E+10	1.3520	8	dark
109	2	63.3	0	118	1.3480	1.00E+10	2.00E+10	2.7000	255	dark
110	2	63.3	0	117	1.3510	1.00E+10	3.00E+10	4.0510	128	dark
111	2	63.3	0	118	1.3460	1.00E+10	4.00E+10	5.3970	128	ref
112	2	63.3	grazing	113	1.3470	1.00E+10	5.00E+10	6.7440	8	dark
113	2	63.3	grazing	114	1.3530	1.00E+10	6.00E+10	8.0970	255	dark
114	2	63.3	grazing	113	1.3540	1.00E+10	7.00E+10	9.4510	128	dark
115	2	63.3	grazing	114	1.3500	1.00E+10	8.00E+10	10.8010	255	ref
116	3	63.3	0	114	1.3490	1.00E+10	1.00E+10	1.3490	8	dark
117	3	63.3	0	115	1.3530	1.00E+10	2.00E+10	2.7020	255	dark
118	3	63.3	0	115	1.3500	1.00E+10	3.00E+10	4.0520	128	dark
119	3	63.3	0	116	1.3530	1.00E+10	4.00E+10	5.4050	128	ref
120	3	63.3	grazing	117	1.3520	1.00E+10	5.00E+10	6.7570	8	dark
121	3	63.3	grazing	113	1.3470	1.00E+10	6.00E+10	8.1040	255	dark
122	3	63.3	grazing	115	1.3480	1.00E+10	7.00E+10	9.4520	128	dark
123	3	63.3	grazing	117	1.3550	1.00E+10	8.00E+10	10.8070	128	ref

Transient degradations were observed, but we did not see any permanent degradation, SEL, or SEFI on all 3 parts.

As a reference, dark pictures with the minimum and the maximum integration time when the parts are not irradiated are shown in Appendix1.

Fig 1 shows a picture taken during irradiation with the minimum integration time investigated. We can see only a few bright spots and the perturbation is minimal.

Fig 1: run 100, irradiation 0 degree, SN1, int time =8

Fig 2 shows a picture taken during irradiation with the maximum integration time investigated. We can see a global change of the dark level. Black color is less saturated and turns to gray. We can also see that the background is not homogeneous. Large gray and light gray horizontal lines alternate.

For the same proton flux than the run with low integration time, there is a larger number of bright spots and these bright spots are larger.

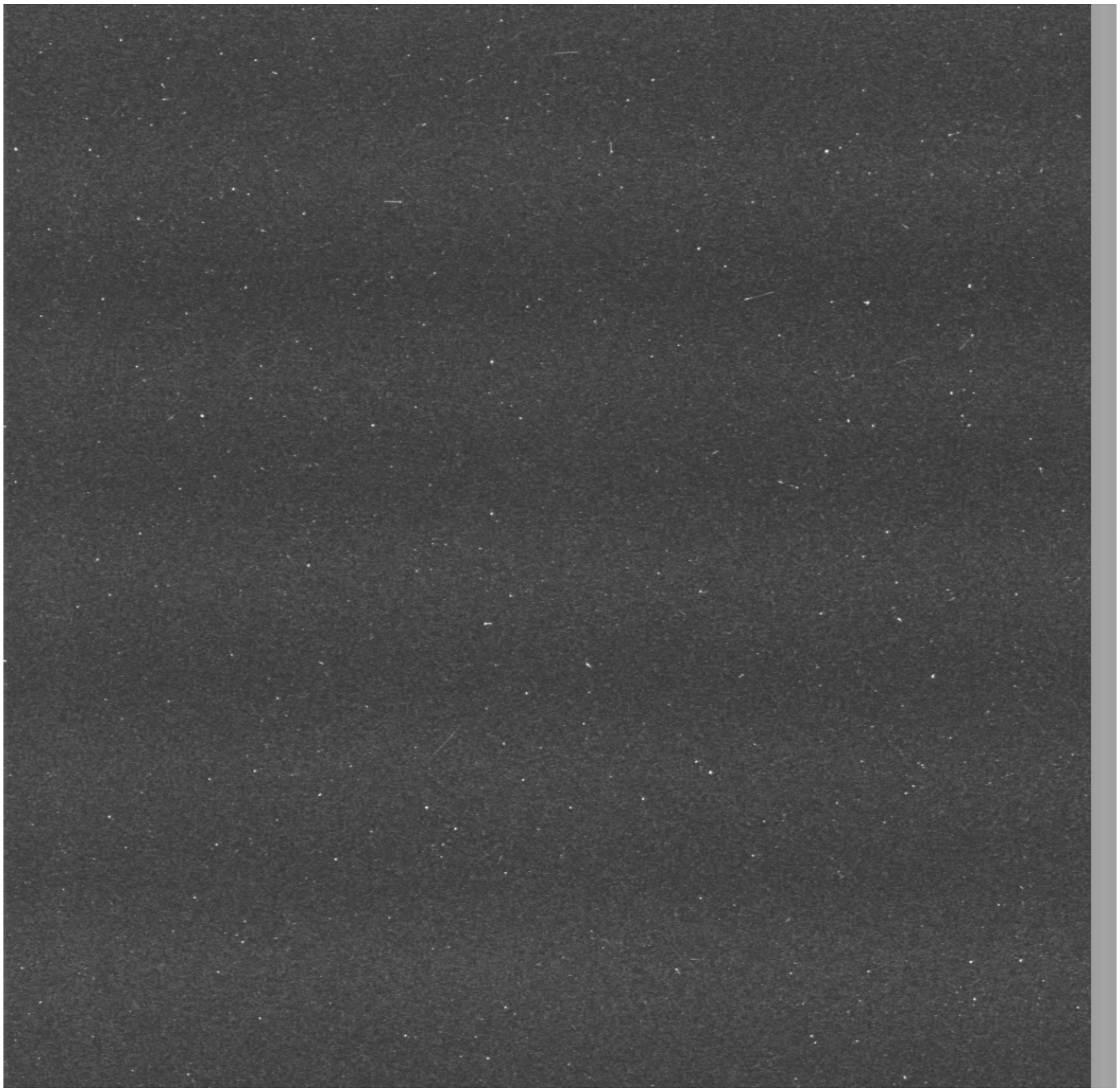

Fig 2: run101, SN1, dark image, int time=255, irradiation 0 degree

Figure 3 shows a dark image taken with an intermediate integration time. The background is darker, but we can still see the alternating horizontal lines. It looks like there are a similar number of bright spots than in Fig 2 and they have a similar size.

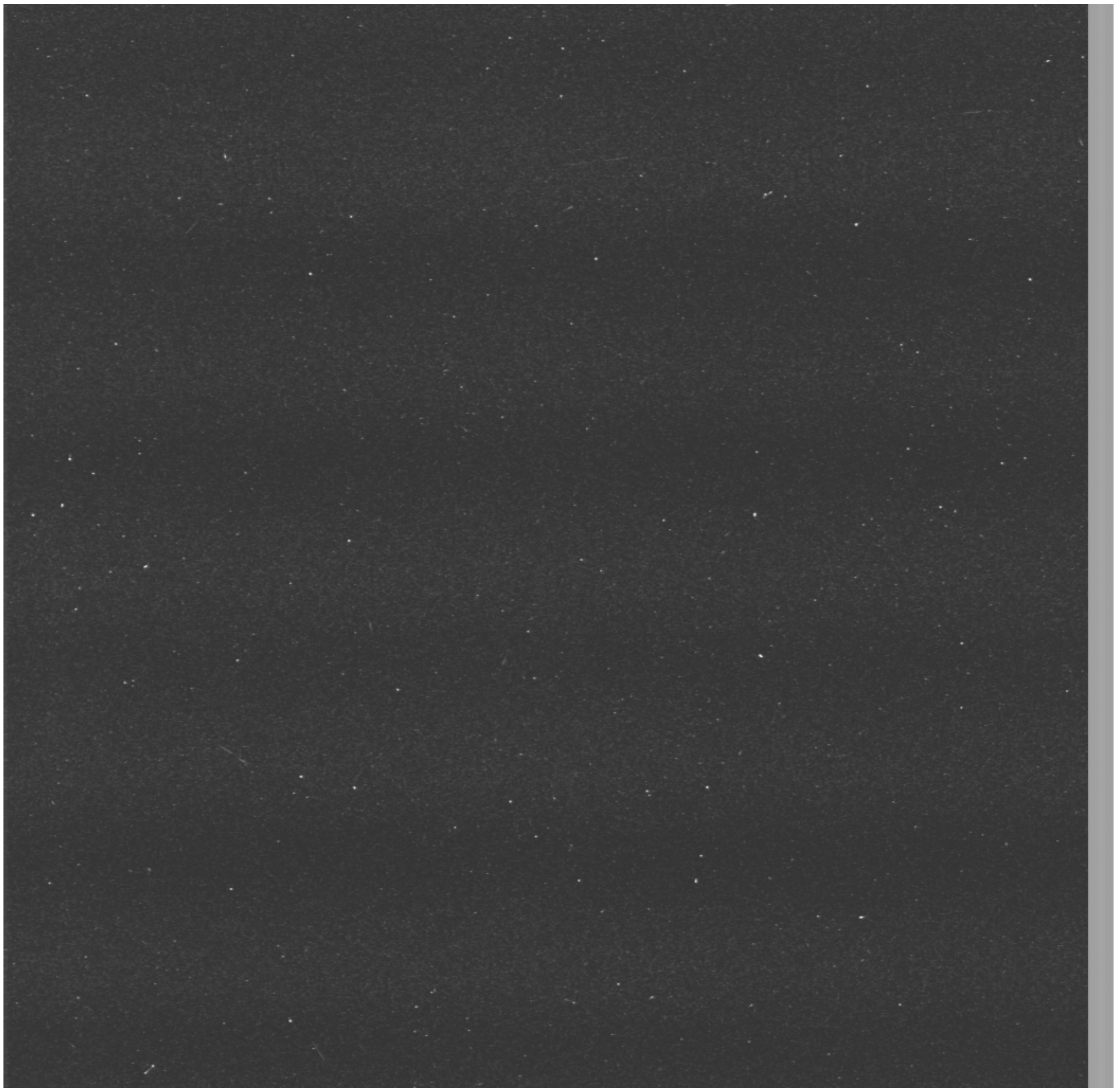

Fig 3: run102, SN1, dark image, int time=128, irradiation 0 degree

The effect of irradiation on the dark images is significant. However, the image is still legible. Fig 4 shows a reference pattern image taken with the maximum integration time. As for the dark image, the image is less saturated, but it is still legible. For this reference image, we do not see the large horizontal lines like in Fig 2 and 3.

Fig 4: run 103, SN1, reference image, int time=255, irradiation at 0 degree

Figure 5 shows a dark image taken with the maximum integration time investigated during an irradiation at grazing incidence. There is no significant difference between irradiation at 0 degree and at grazing incidence.

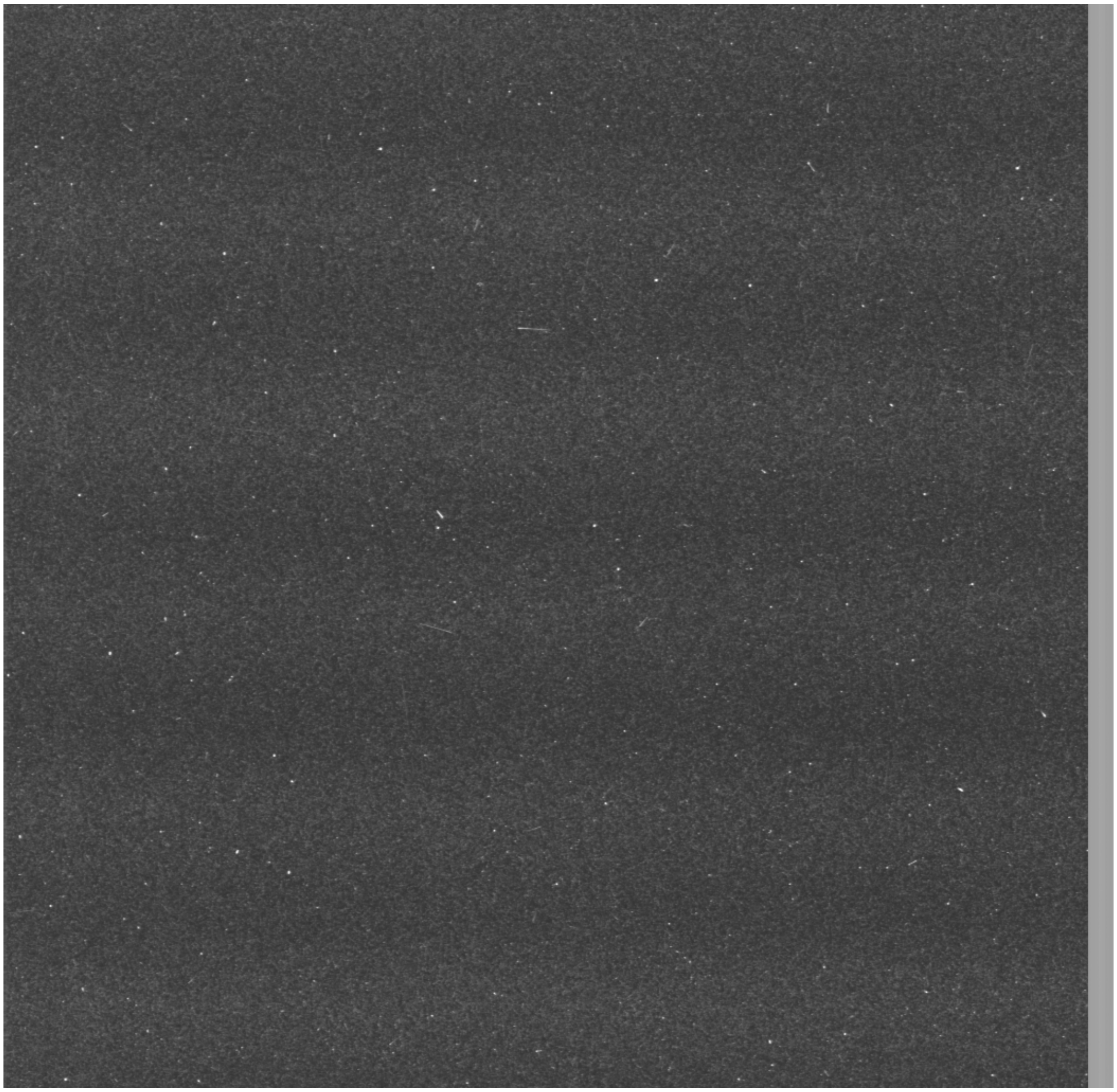

Fig 5: run 105, dark image, int time =255, irradiation at grazing incidence

Appendix 1: dark images when the devices are not irradiated

run 100 before irradiation, int. time=8, SN1

run 101 before irradiation, int time=255, SN1

Appendix 2:

- http://www.fillfactory.com/htm/products/htm/star1000/star1000.htm